

METHOD AND APPARATUS FOR APPLYING A
POLYCHROMATIC COATING ONTO A SUBSTRATE

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CROSS-REFERENCE TO RELATED APPLICATIONS

- This patent application is related to U.S. Patent Application Serial No. 09/____ entitled "Method and Apparatus for Dynamically Coating a Substrate"; and U.S. Patent Application Serial No. 09/____ entitled "Method and Apparatus for Applying a Coating onto a Substrate", both of Vincent P. Dattilo and each filed concurrently with the present application, each of which is herein incorporated by reference.

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Field of the Invention

This invention relates generally to applying coatings, e.g., basecoats and/or clearcoats, onto automotive substrates and, more particularly, to coating systems and methods useful for applying effect pigment-containing polychromatic coatings onto automotive substrates using bell applicators.

BACKGROUND OF THE INVENTION

Today's automobile bodies are treated with multiple layers of coatings which not only enhance the appearance of the automobile, but also provide protection from corrosion, chipping, ultraviolet light, acid rain and other environmental conditions which can deteriorate the coating appearance and underlying car body. In a typical automotive coating method, a basecoat is applied to the substrate to provide the substrate with a desired color. The basecoated substrate may be dehydrated and cooled and then one or more clearcoats are applied as a protective coating over the basecoat.

Automotive finishes that show significant contrast in color and darkness depending upon the viewing angle, often referred to as "polychromatic effect", "travel" or "flop", are highly desirable in the present automotive market. A desired

polychromatic effect is one in which the coated substrate appears light in direct observation and darker when observed at an angle of about 60° to about 80°, preferably with a shift in color from direct to angular observation. This 5 polychromatic effect is currently achieved by using a basecoat composition which contains a combination of transparent organic and/or inorganic pigments to provide color and also an "effect pigment", such as metal or mica flakes, which provides the desired polychromatic effect when properly oriented. To 10 achieve the desired polychromatic effect, the majority of the effect pigment flakes should be oriented to lay substantially parallel to the surface being coated.

In order to achieve the desired polychromatic effect, i.e., proper orientation of the effect pigment flakes, the 15 basecoat is typically applied in a multi-step method using two different coating techniques. A bell applicator is used to apply the first or underlying basecoat layer(s) and a reciprocating gun applicator is used to apply the second or outer basecoat layer(s) over the first basecoat layer.

20 With respect to the first basecoat layer(s), conventional bell applicators and bell applicator systems are described, for example, in U.S. Patent Nos. 4,714,044; 4,532,148; and 4,539,932, which are herein incorporated by reference. While these references disclose the use of bell applicators to apply 25 automotive coatings, they do not address the orientation problems of depositing the effect pigments, which orientation is critical to achieving the desired polychromatic effect.

Bell applicators offer a relatively high total transfer efficiency (about 80%). However, a drawback of bell 30 applicators is that they produce very poor metallic orientation when depositing effect-pigmented coatings. Because bell-applied spray coatings are typically very dry when deposited upon the substrate, the effect pigment flakes do not orient properly in the applied coating film. In a 35 typical bell spray method, polychromatic colors appear dark in

direct face observation and light in angular observation due to misorientation of the effect pigment flakes, thus minimizing or even reversing the desired polychromatic effect. This "bell color effect" is highly undesirable and severely 5 limits the colors available as marketing and styling tools for the automaker.

In order to prevent this bell color effect, the outer basecoat layer comprising the same color-pigmented and fully effect-pigmented coating material as the first basecoat layer 10 typically is applied using a reciprocating gun applicator. Although gun applicators provide much lower transfer efficiency (about 30-40%), they produce a basecoat layer in which more of the effect pigments are properly oriented to produce the desired polychromatic effect.

15 Thus, to obtain a desired range of colors while maintaining the desired polychromatic effect, automakers compromise efficiency and utilize a method incorporating a lower transfer efficient reciprocating gun coating device. Using a reciprocating gun increases the overall cost of the 20 coating method since more of the coating material is lost due to poor transfer efficiency.

Another problem associated with known coating application methods is achieving a uniform coating over the substrate. In conventional multi-applicator coating methods, each applicator 25 is individually controlled with little regard for how each applicator affects the overall coating system. For example, automotive production spray methods typically utilize multiple coating applicators, e.g., five to nine applicators per coating zone with several zones, that are intended to act in 30 unison to uniformly coat complex geometry vehicle shapes.

Acting in unison means producing atomized coating droplets that are of substantially equal size and distribution from each applicator. While traditional applicator control functions are well documented, current multiple applicator 35 control systems focus almost exclusively on individual

applicator control without coordinating the droplet size and distribution among multiple applicators.

As will be understood by one of ordinary skill in the automotive coating art, it would be advantageous to apply an effect-pigment containing basecoat or basecoat layer over a substrate using one or more bell applicators if the desired polychromatic effect could be achieved. Further, it would be advantageous to decrease the total amount of effect pigment used to obtain a desired polychromatic effect to reduce coating cost. It also would be advantageous to provide an applicator control method for a multi-applicator system which allows the applicators to have independent control features but which coordinates those controls based on a common coating system control parameter to promote the formation of substantially uniform droplets.

SUMMARY OF THE INVENTION

A method is provided for coating a substrate. The method comprises applying a first waterborne coating material over the substrate by one or more bell applicators, the first coating material being substantially free of effect pigment. A second waterborne coating material is applied over the first coating material by one or more bell applicators, the second coating material comprising effect pigment. Between application of the first and second basecoat materials onto the substrate, the first basecoat material on the substrate can be exposed to air having a temperature ranging from about 50°F (10.0°C) to about 90°F (32.5°C), a relative humidity of about 40% to about 80% and an air velocity at the surface of the first basecoat material of about 20 FPM (0.10 meter/sec) to about 150 FPM (0.76 meter/sec) for a period of about 10 to about 180 seconds.

A basecoat formed in accordance with the invention comprises a first basecoat layer substantially free of effect pigment and applied by one or more bell applicators over the

substrate. A second basecoat layer comprising effect pigment and applied by one or more bell applicators is deposited over the first basecoat layer.

A coating application system is also provided. The
5 system comprises a first supply of one or more first coating components which are substantially free of effect pigment and a second supply of one or more second coating components which comprise effect-pigment. At least one mixer is provided for dynamically mixing one or more of the first coating components
10 or one or more of the second coating components to form a mixed coating material. The mixed coating material is received from the mixer and applied over the substrate by one or more bell applicators.

A method of controlling a multi-bell applicator system
15 comprises determining values of bell rotational speed, shaping air velocity and coating flow rate to produce a desired coating droplet uniformity, using the determined values to form a control ratio of atomization energy (rotational speed multiplied by shaping air volume) to coating flow rate, and
20 controlling the rotational speed, shaping air velocity and coating flow rate of each bell applicator of the system to substantially maintain the control ratio.

A complete understanding of the invention will be obtained from the following description when taken in
25 connection with the accompanying drawing figures wherein like reference characters identify like parts throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic block diagram (not to scale) of a
30 coating system according to the present invention;

Fig. 2 is a schematic block diagram (not to scale) of an alternative embodiment of a coating system according to the present invention;

Fig. 3 is a schematic diagram of an exemplary dynamic
35 coating device according to the present invention;

Fig. 4 is a schematic block diagram (not to scale) of an alternative embodiment of a coating system according to the invention;

Fig. 5 is a schematic diagram of a dynamic coating device 5 according to the present invention; and

Fig. 6 is a side elevational view of a dynamic coating system according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 For purposes of the description herein, the term "over" means above but not necessarily adjacent to. Other than in the operating examples, or where otherwise indicated, all numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification and claims 15 are to be understood as being modified in all instances by the term "about". Also, as used herein, the term "polymer" is meant to refer to oligomers, homopolymers and copolymers.

Fig. 1 schematically depicts a coating system 10 incorporating features of the invention. This system 10 is 20 suitable for coating metal or polymeric substrates in a batch or continuous method. In a batch method, the substrate is stationary during each treatment step, whereas in a continuous method the substrate is in continuous movement along an assembly line. The present invention will be discussed 25 generally in the context of coating a substrate in a continuous assembly line, although the method is also useful for coating substrates in a batch method.

Useful substrates that can be coated according to the method of the present invention include metal substrates, 30 polymeric substrates, such as thermoset materials and thermoplastic materials, and combinations thereof. Useful metal substrates that can be coated according to the method of the present invention include ferrous metals such as iron, steel, and alloys thereof, non-ferrous metals such as 35 aluminum, zinc, magnesium and alloys thereof, and combinations

thereof. Preferably, the substrate is formed from cold rolled steel, electrogalvanized steel such as hot dip electro-galvanized steel or electrogalvanized iron-zinc steel, aluminum or magnesium.

5 Useful thermoset materials include polyesters, epoxides, phenolics, and polyurethanes such as reaction injected molding urethane (RIM) thermoset materials and mixtures thereof.

Useful thermoplastic materials include thermoplastic polyolefins such as polyethylene and polypropylene, polyamides 10 such as nylon, thermoplastic polyurethanes, thermoplastic polyesters, acrylic polymers, vinyl polymers, polycarbonates, acrylonitrile-butadiene-styrene (ABS) copolymers, EPDM rubber, copolymers and mixtures thereof.

Preferably, the substrates are used as components to 15 fabricate automotive vehicles, including but not limited to automobiles, trucks and tractors. The substrates can have any shape, but are preferably in the form of automotive body components such as bodies (frames), hoods, doors, fenders, bumpers and/or trim for automotive vehicles.

20 The present invention will be discussed generally in the context of coating a metallic automobile body substrate. One skilled in the art would understand that the methods and devices of the present invention also are useful for coating non-automotive metal and/or polymeric substrates, such as 25 motorcycles, bicycles, appliances, and the like.

With reference to Fig. 1, a metal substrate 12 can be cleaned and degreased and a pretreatment coating, such as CHEMFOS 700® zinc phosphate or BONAZINC® zinc-rich pretreatment (each commercially available from PPG Industries, 30 Inc. of Pittsburgh, Pennsylvania), can be deposited over the surface of the metal substrate 12 at a pretreatment zone 14. Alternatively or additionally, one or more electrodepositable coating compositions (such as POWER PRIME® coating system commercially available from PPG Industries, Inc. of 35 Pittsburgh, Pennsylvania) can be electrodeposited upon at

least a portion of the metal substrate 12 at an electrodeposition zone 16. Useful electrodeposition methods and electrodepositable coating compositions include conventional anionic or cationic electrodepositable coating compositions, such as epoxy or polyurethane-based coatings. Suitable electrodepositable coatings are discussed in U.S. Patent Nos. 4,933,056; 5,530,043; 5,760,107 and 5,820,987, which are incorporated herein by reference.

The coated substrate 12 can be rinsed, heated and cooled and then a primer layer can be applied to the substrate 12 at a primer zone 18 before subsequent rinsing, baking, cooling, sanding and sealing operations. The primer coating composition can be liquid, powder slurry or powder (solid), as desired. The liquid or powder slurry primer coating can be applied to the surface of the substrate 12 by any suitable coating method well known to those skilled in the automotive coating art, for example by dip coating, direct roll coating, reverse roll coating, curtain coating, spray coating, brush coating and combinations thereof. Powder coatings are generally applied by electrostatic deposition. The method and apparatus for applying the primer composition to the substrate 12 is determined in part by the configuration and type of substrate material.

The liquid or powder slurry primer coating composition generally comprises one or more film-forming materials, volatile materials and, optionally, coloring pigments. Volatile materials are not present in the powder coating composition. Preferably, the primer coating composition, whether liquid, powder slurry or powder, comprises one or more thermosetting film-forming materials, such as polyurethanes, acrylics, polyesters, epoxies, and crosslinking materials. The primer or primer components can include urethane compositions, which may include filler material such as flow/wetting agents, barium sulfate and/or magnesium silicate

for solids content, silicone oils for mar resistance, fumed silicas, and the like.

Non-limiting examples of useful primers are disclosed in U.S. Patent Nos. 4,971,837; 5,492,731 and 5,262,464, which are 5 incorporated herein by reference. The amount of film-forming material in the primer generally ranges from about 37 to about 60 weight percent on a basis of total resin solids weight of the primer coating composition.

In an important aspect of the present invention, the 10 basecoat is applied over the substrate 12 in a multi-step method at a basecoat zone 20 comprising one or more basecoat application stations. For example, a first basecoat station 22 has one or more applicators, e.g., bell applicators 24, in flow communication with a first basecoat material supply 26 15 which supplies at least one first basecoat material or component to the bell applicator(s) 24. A second basecoat station 28 has one or more applicators, e.g., bell applicators 30, in flow communication with a second basecoat material supply 32 which supplies at least one second basecoat material 20 or component to the bell applicator(s) 30.

As described more fully below, the first basecoat material can be applied, e.g., sprayed, over the substrate 12 by one or more bell applicators 24 at the first basecoat station 22 in one or more spray passes to form a first 25 basecoat layer over the substrate 12 and the second basecoat material can be sprayed over the first basecoat material at the second basecoat station 28 by one or more bell applicators 30 in one or more spray passes to form a second basecoat layer. A composite basecoat of the invention is thus formed 30 by one or more second basecoat layers applied over one or more first basecoat layers. As used herein, the terms "layer" or "layers" refer to general coating regions or areas which can be applied by one or more spray passes but do not necessarily mean that there is a distinct or abrupt interface between

adjacent layers, i.e., there can be some migration of components between the first and second basecoat layers.

- In a preferred aspect of the present invention, both the first and second basecoat materials are liquid, preferably 5 waterborne, coating materials. As used herein, the term "waterborne" means that the solvent or carrier fluid for the coating material primarily or principally comprises water. The first basecoat material generally comprises a film-forming material or binder, volatile material and is substantially 10 free of effect pigment. Preferably, the first basecoat material comprises a crosslinkable coating composition comprising at least one thermosettable film-forming material, such as acrylics, polyesters (including alkyds), polyurethanes and epoxies, and at least one crosslinking material. 15 Thermoplastic film-forming materials such as polyolefins also can be used. The amount of film-forming material in the liquid basecoat material generally ranges from about 40 to about 97 weight percent on a basis of total weight solids of the basecoat material.
- 20 Suitable acrylic polymers include copolymers of one or more of acrylic acid, methacrylic acid and alkyl esters thereof, such as methyl methacrylate, ethyl methacrylate, hydroxyethyl methacrylate, butyl methacrylate, ethyl acrylate, hydroxyethyl acrylate, butyl acrylate and 2-ethylhexyl acrylate, optionally together with one or more other polymerizable ethylenically unsaturated monomers including vinyl aromatic compounds such as styrene and vinyl toluene, nitriles such as acrylonitrile and methacrylonitrile, vinyl and vinylidene halides, and vinyl esters such as vinyl acetate. 25 Other suitable acrylics and methods for preparing the same are disclosed in U.S. Patent No. 5,196,485 at column 11, lines 16-60, which are incorporated herein by reference.

Polyesters and alkyds are other examples of resinous binders useful for preparing the basecoating composition. 35 Such polymers can be prepared in a known manner by

condensation of polyhydric alcohols, such as ethylene glycol, propylene glycol, butylene glycol, 1,6-hexylene glycol, neopentyl glycol, trimethylolpropane and pentaerythritol, with polycarboxylic acids such as adipic acid, maleic acid, fumaric acid, phthalic acids, trimellitic acid or drying oil fatty acids.

Polyurethanes also can be used as the resinous binder of the basecoat. Useful polyurethanes include the reaction products of polymeric polyols such as polyester polyols or acrylic polyols with a polyisocyanate, including aromatic diisocyanates such as 4,4'-diphenylmethane diisocyanate, aliphatic diisocyanates such as 1,6-hexamethylene diisocyanate, and cycloaliphatic diisocyanates such as isophorone diisocyanate and 4,4'-methylene-bis(cyclohexyl isocyanate).

Suitable crosslinking materials include aminoplasts, polyisocyanates, polyacids, polyanhydrides and mixtures thereof. Useful aminoplast resins are based on the addition products of formaldehyde, with an amino- or amido-group carrying substance. Condensation products obtained from the reaction of alcohols and formaldehyde with melamine, urea or benzoguanamine are most common. Useful polyisocyanate crosslinking materials include blocked or unblocked polyisocyanates such as those discussed above for preparing the polyurethane. Examples of suitable blocking agents for the polyisocyanates include lower aliphatic alcohols such as methanol, oximes such as methyl ethyl ketoxime and lactams such as caprolactam. The amount of the crosslinking material in the basecoat coating composition generally ranges from about 5 to 30 about 50 weight percent on a basis of total resin solids weight of the basecoat coating composition.

Although the first basecoat material is preferably a waterborne coating material, the first basecoat material also can comprise one or more other volatile materials such as organic solvents and/or amines. Non-limiting examples of

- useful solvents which can be included in the basecoat material, in addition to any provided by other coating components, include aliphatic solvents such as hexane, naphtha, and mineral spirits; aromatic and/or alkylated
- 5 aromatic solvents such as toluene, xylene, and SOLVESSO 100; alcohols such as ethyl, methyl, n-propyl, isopropyl, n-butyl, isobutyl and amyl alcohol, and m-pyrol; esters such as ethyl acetate, n-butyl acetate, isobutyl acetate and isobutyl isobutyrate; ketones such as acetone, methyl ethyl ketone,
- 10 methyl isobutyl ketone, diisobutyl ketone, methyl n-amyl ketone, and isophorone, glycol ethers and glycol ether esters such as ethylene glycol monobutyl ether, diethylene glycol monobutyl ether, ethylene glycol monohexyl ether, propylene glycol monomethyl ether, propylene glycol monopropyl ether,
- 15 ethylene glycol monobutyl ether acetate, propylene glycol monomethyl ether acetate, and dipropylene glycol monomethyl ether acetate. Useful amines include alkanolamines.

Other additives, such as UV absorbers, rheology control agents or surfactants can be included in the first basecoat material, if desired. Additionally, the first basecoat material can include color (non-effect) pigments or coloring agents to provide the first basecoat material with a desired color. Non-limiting examples of useful color pigments include iron oxides, lead oxides, carbon black, titanium dioxide and colored organic pigments such as phthalocyanines. As discussed above, the first basecoat material is substantially free of effect pigments, such as mica flakes, aluminum flakes, bronze flakes, coated mica, nickel flakes, tin flakes, silver flakes, copper flakes and combinations thereof. As used

20 herein, "substantially free of effect pigment" means that the basecoat material comprises less than about 3% by weight of effect pigment on a basis of total weight of the first basecoat material, more preferably less than about 1% by weight, and most preferably is free of effect pigment.

The solids content of the liquid basecoat material generally ranges from about 15 to about 60 weight percent, and preferably about 20 to about 50 weight percent. In an alternative embodiment, the first basecoat material can be 5 formulated from functional materials, such as primer components, which provide, for example, chip resistance to provide good chip durability and color appearance, possibly eliminating the need for a separate spray-applied primer.

The second basecoat material contains similar components 10 (such as film forming material and crosslinking material) to the first basecoat material but further comprises one or more effect pigments. Non-limiting examples of effect pigments useful in the practice of the invention include mica flakes, aluminum flakes, bronze flakes, coated mica, nickel flakes, 15 tin flakes, silver flakes, copper flakes and combinations thereof. The specific pigment to binder ratio can vary widely so long as it provides the requisite hiding at the desired film thickness and application solids and desired polychromatic effect. The amount of effect pigment in the 20 second basecoat material is that which is sufficient to produce a desired polychromatic effect. Preferably, the amount of effect pigment ranges from about 0.5 to about 40 weight percent on a basis of total weight of the second basecoat material, and more preferably about 3 to about 15 25 weight percent.

Examples of waterborne basecoat materials suitable for use as first and/or second basecoat materials include those disclosed in U.S. Patent Nos. 4,403,003; 5,401,790 and 5,071,904, which are incorporated by reference herein. Also, 30 waterborne polyurethanes such as those prepared in accordance with U.S. Patent No. 4,147,679 can be used as the resinous film former in the basecoat materials, which is incorporated by reference herein. Suitable film formers for organic solvent-based base coats are disclosed in U.S. Patent No. 35 4,220,679 at column 2, line 24 through column 4, line 40 and

U.S. Patent No. 5,196,485 at column 11, line 7 through column 13, line 22, which are incorporated by reference herein.

With reference to Fig. 1, the first basecoat material is preferably applied over the substrate 12 at the first basecoat station 22 using one or more bell applicators 24. The first basecoat layer is applied to a thickness of about 5 to about 30 microns, and more preferably about 8 to about 20 microns. If multiple bell applicators 24 are used in the first basecoat station 22, the atomization for each of the bell applicators 10 24 is controlled as described more fully below to promote the formation of coating droplets of substantially uniform size from each applicator 24 to promote the formation of a uniformly thick layer on the substrate 12.

As will be understood by one of ordinary skill in the automotive coating art, bell applicators typically include a body portion or bell having a rotating cup. The bell is connected to a high voltage source to provide an electrostatic field between the bell and the substrate. The electrostatic field shapes the charged, atomized coating material discharged 20 from the bell into a cone-shaped pattern, the shape of which can be varied by shaping air ejected from a shaping air ring on the bell. Non-limiting examples of suitable conventional bell applicators include Eco-Bell or Eco-M Bell applicators commercially available from Behr Systems Inc. of Auburn Hills, 25 Michigan; Meta-Bell applicators commercially available from ABB/Ransburg Japan Limited of Tokyo, Japan; G-1 Bell applicators commercially available from ABB Flexible Automation of Auburn Hills, Michigan; or Sames PPH 605 or 607 applicators commercially available from Sames of Livonia, 30 Michigan; or the like. The structure and operation of bell applicators will be understood by one of ordinary skill in the art and hence will not be discussed in further detail herein.

The first basecoat material can be a premixed, waterborne material substantially free of effect pigment as described 35 above and supplied to the one or more bell applicators 24 in

the first basecoat station 22 in conventional manner, e.g., by metering pumps. However, in an important aspect of the invention, the first basecoat material applied over the substrate 12 at the first basecoat station 22 can be
5 dynamically mixed from two or more individual components during the coating method. As used herein, "dynamically mixed" means mixing or blending two or more components to form a mixed or blended material as the components flow toward an applicator, e.g., a bell applicator, during the coating
10 process.

To better understand the dynamic mixing concept of the invention, an exemplary dynamic coating device 86 according to the present invention (shown in Fig. 3) will now be discussed. The coating device 86 comprises a plurality of coating
15 component supplies, such as a first component supply 76 containing a first coating component, a second component supply 80 containing a second coating component and a third coating component supply 88 containing a third coating component, each of which is in flow communication with an
20 applicator conduit 90 via respective coating conduits 92. Transport devices, such as fixed or variable displacement pumps 94, are used to move one or more selected components through the conduits 90, 92. A mixer 96, e.g., a conventional dynamic flow mixer such as a pipe mixer (part no. 511-353)
25 commercially available from Graco Equipment, Inc. of Minneapolis, Minnesota, is located in the applicator conduit 90 and at least one applicator, e.g. a bell applicator 98, is located downstream of the mixer 96. A conventional color change apparatus 100 or similar control device, such as a
30 Moduflow Colorchange Stack commercially available from Sames of Livonia, Michigan can be used to control the flow rate of the various coating components received from the supplies 76, 80 and/or 88. While the dynamic mixing concept of the invention is discussed herein with reference to supplying the
35 mixed material to one or more bell applicators, the dynamic

mixing process of the invention is not limited to use with bell applicators but can be used with other types of applicators, such as reciprocating gun applicators.

For purposes of the present discussion regarding application of the first basecoat layer at the first basecoat station 22, the first, second and third coating component supplies 76, 80 and 88 may each comprise a waterborne coating component substantially free of effect pigment and each preferably of a differing primary color such that the color of the first coating material applied over the substrate 12 can be varied by changing the amounts of the selected coating components supplied to the bell applicator 98. Additional examples of dynamic coating devices of the invention which are also suitable for application of the first and/or second basecoat layers over the substrate 12 are discussed below.

As mentioned above, if more than one bell applicator 24 is used at the first basecoat station 22, in a preferred embodiment an atomizer or applicator control method of the invention is utilized in which multiple applicator performance is managed using individual atomizer control values but selected variables are constrained by a single mathematical ratio (or range) of optimized atomization energy to coating flow rate (AE:CF) through the applicator. Thus, a uniform control technique is provided for managing multiple spray applicators used in unison in the coating system 10.

The inventor has discovered that there is a relationship between the droplet size and/or distribution of the droplets discharged from an atomizer and the ratio of atomization energy to coating flow rate for the atomizer. Atomization energy (AE) provides the physical or mechanical force for liquid breakup. With respect to bell atomizers, two important factors in determining atomization energy are the bell cup rotation speed and the volume of shaping air to the bell. Generally, as the rotational speed of the bell increases, the mean droplet size of material discharged from the bell

decreases. Also, as the shaping air volume increases, the droplet concentration or size distribution is altered, generally resulting in increased mean droplet size. The product of the bell speed multiplied by the shaping air volume provides a useful approximation of the atomization energy for a bell applicator. However, it is to be understood that other factors, such as the diameter of the cup, the number and size of holes in the shaping ring, the size of the discharge orifice, and the distance between the bell and the substrate can also influence the atomization energy.

Coating flow rate (CF) is the liquid coating quantity per unit time available for breakup into droplets. Both atomization energy and coating flow rate impact coating atomization. When one component is changed without consideration of the other, the entire atomization method may radically change. In prior systems, final film build was routinely adjusted through changes in CF without consideration of AE. In so doing, it has now been discovered that the droplet size and distribution was inconsistently varied, adversely impacting the quality of the final film.

In the practice of the invention, predetermined atomizer control parameters are established that yield an acceptable coating for a particular coating system. The individual parameter values, e.g., cup rotation speed, shaping air supply and coating flow rate, are chosen by correlating each of these variables to droplet size and/or distribution curves (in laboratory) or by actual coated substrate tests which meet with customer approval (in lab or online). Once the desired values of each parameter are selected, a control ratio of the atomization energy, e.g., (bell cup speed (S) multiplied by shaping air supply (V, e.g., volume per minute or pressure), to the coating flow rate (CF) is calculated to yield a (AE/CF) control ratio in which $(AE/CF) = (S \cdot V / CF)$ for the coating system. This control ratio becomes the control management set point for all bell applicators in the given application zone.

or the coating system. This ratio control technique allows coating film builds to remain fully adjustable by changes in the coating flow rate for a given applicator while the other control variables, e.g., cup rotation speed and/or shaping air supply, are varied in response to any change in the coating flow rate to automatically rebalance in proportion to the shift in coating flow rate to reestablish the desired control ratio.

The ratio control method of the invention allows all applicators to have independent control features but balances those controls against a single common control ratio (AE/CF), thereby promoting an equal spray dynamic (droplet size and distribution) for all applicators within a given zone or system. In the practice of the invention, the rotational speed, shaping air supply and coating flow rate for each bell applicator in a given coating zone are preferably controlled to produce a similar droplet distribution, preferably a distribution with about 40% to about 70% of the droplets being about 15 to about 40 microns in size. Droplets falling outside this size range preferably are about 10 to about 85 microns in size.

It should be understood that the atomizer control method of the invention is not limited to use with bell applicators. For gun applicators, for example, the principle atomization parameters for controlling droplet size and distribution are believed to be the atomization air supplied (e.g., volume per minute or pressure) to the gun and the fan air supplied (e.g., volume per minute or pressure). Therefore, the control ratio for gun applicators would be (atomization air supplied x fan air supplied)/coating flow rate. However, it is to be understood that the atomization energy for gun applicators can be influenced by such factors as, for example, the configuration of the air cap, the size of the discharge orifice, the needle position, the number of gun heads, and the distance between the gun and the substrate.

With continued reference to Fig. 1, the first basecoat material can be applied over the substrate at the first basecoat station 22 utilizing a conventional spraybooth having an environmental control system designed to control one or more of the temperature, relative humidity, and/or air flow rate in the spraybooth. However, as discussed below, in the preferred practice of the invention, special temperature or humidity controls generally are not required during the spray application of the first basecoat layer at the first basecoat station 22.

After the first basecoat layer is applied at the first basecoat station 22, the coated substrate 12 preferably enters a first flash chamber 40 in which the air velocity, temperature and humidity are controlled to control evaporation from the deposited first basecoat layer to form a first basecoat layer with sufficient moisture content or "wetness" such that a substantially smooth, substantially level film of substantially uniform thickness is obtained without sagging.

Preferably within about 15 to about 45 seconds after completion of the application of the first basecoat layer, the substrate 12 is positioned at the entrance of the first flash chamber 40 and slowly moved therethrough in assembly-line manner at a rate which promotes the volatilization and stabilization of the first basecoat layer. The rate at which the substrate 12 is moved through the first flash chamber 40 depends in part on the length and configuration of the first flash chamber 40 but the substrate 12 is preferably in the first flash chamber 40 for about 10 to about 180 seconds, preferably about 20 to about 60 seconds. The air is preferably supplied to the first flash chamber 40 by a blower or dryer 62. A non-limiting example of a suitable blower is an ALTIVARR 66 blower commercially available from Square D Corporation. The air is circulated at about 20 FPM (0.10 m/s) to about 150 feet per minute (FPM) (0.76 meters/second) air velocity at the surface of the coating, preferably about 50

FPM (0.25 m/s) to about 80 FPM (0.41 meters/sec) air velocity, and is heated to a temperature of about 50°F (10.0°C) to about 90°F (32.5°C), preferably about 70°F (21.1°C) to about 80°F (26.7°C) and more preferably about 70°F (21.1°C) to about 75°F (24.0°C) and relative humidity of about 40% to about 80%, preferably about 60% to about 70%, and more preferably about 65% relative humidity. The air can be recirculated through the first flash chamber 40 since it is not located in a spray zone and therefore is essentially free of paint particulates.

5 While in the preferred embodiment described above the substrate 12 moves through the flash chamber 40, it is to be understood that the substrate 12 also can be stopped in the flash chamber 40.

Contrary to previous thinking, it is believed that the quality of a deposited coating material is more a function of the atomization method and drying conditions subsequent to spray application than the temperature and humidity within a conventional spray booth during application of the coating. It now has been determined that the evaporation rate from the surface of the applied film can be a significant factor in deposited droplet film knit and coalescence. The coating method of the invention, utilizing a flash chamber 40 of the invention between basecoat layer applications, focuses on temperature and humidity control of the wet droplet applied film rather than on environmental control during the spray process itself, contrary to previous coating methods. Utilizing the flash chamber 40 in accordance with the invention eliminates the need for a conventional environmentally controlled spraybooth at the first basecoat station 22 when applying the first basecoat layer.

The substrate 12 is conveyed from the flash chamber 40 and the second, effect pigment-comprising basecoat layer is applied over the first basecoat layer at the second basecoat station 28 by one or more bell applicators 30, preferably 35 utilizing the atomizer control process described above to

maximize atomization and optimize droplet size and wetness. While the second basecoat material can be applied in a conventional spraybooth, in a preferred practice of the invention special temperature or humidity controls generally are not required. The second basecoat material can be a premixed, effect pigment-comprising waterborne coating material as described above. Alternatively the second basecoat material can be dynamically mixed using a coating device similar to the coating device 86 discussed above but in which one or more of the coating components in the coating component supplies 76, 80 or 88 comprise effect pigment or effect-pigmented and/or colored coating components which can be dynamically mixed to form the second basecoat material. The thickness of the second basecoat layer is preferably about 3 to about 15 microns, more preferably about 5 to about 10 microns.

One skilled in the art would understand that multiple layers of the first and/or second basecoat materials can be applied, if desired. Also, alternating layers can be applied. The thickness of the composite basecoat, i.e., the combined thickness of the first and second basecoat layers applied to the substrate 12, can vary based upon such factors as the type of substrate and intended use of the substrate, i.e., the environment in which the substrate is to be placed and the nature of the contacting materials. Generally, the thickness of the overall basecoat ranges from about 10 to about 38 microns, and preferably about 12 to about 30 microns.

Applying the effect pigment-containing second basecoat layer over the first basecoat layer after stabilization of the first basecoat material in the flash chamber 40 has been found to permit the effect pigment in the second basecoat layer to correctly orient to provide the desired polychromatic effect even when using bell applicators for the application of both basecoat layers.

The first basecoat layer can be applied as a full-opaque functional coat or a semi-opaque color pigmented coat. The method of the invention provides a deep, color-rich base to which the metallic second basecoat layer can be applied. In 5 the composite basecoat of the present invention, the effect pigment provided in the second basecoat layer preferably is present only in about the outer 60%, more preferably the outer 40% of the total composite basecoat thickness. This coating procedure thus utilizes less effect pigment than conventional 10 basecoats which use effect pigment throughout the entire basecoat thickness and hence is more economically desirable to automakers.

With continued reference to Fig. 1, although not preferred, after application of the second basecoat layer, the 15 composite basecoat can be flashed in a flash chamber 40 as described above before further processing. However, it is preferred that the composite basecoat formed over the surface of the substrate 12 is dried or cured at a conventional drying station 44 after application of the second basecoat layer. For 20 waterborne basecoats, "dry" means the almost complete absence of water from the composite basecoat. Drying the basecoat enables application of a subsequent protective clearcoat, as described below, such that the quality of the clearcoat will not be adversely affected by further drying of the basecoat. 25 If too much water is present in the basecoat, the subsequently applied clearcoat can crack, bubble or "pop" during drying of the clearcoat as water vapor from the basecoat attempts to pass through the clearcoat.

The drying station 44 can comprise a conventional drying 30 oven or drying apparatus, such as an infrared radiation oven commercially available from BGK-ITW Automotive Group of Minneapolis, Minnesota. Preferably, the basecoat is dried to form a film which is substantially uncrosslinked, i.e., is not heated to a temperature sufficient to induce significant 35 crosslinking, and there is substantially no chemical reaction

between the thermosettable film-forming material and the crosslinking material.

After the basecoat on the substrate 12 has been dried (and cured and/or cooled, if desired) in the drying station 5 44, a clearcoat is applied over the basecoat at a clearcoat zone 46 comprising at least one clearcoat station, e.g., first and second clearcoat stations 48 and 50, respectively, each having one or more bell applicators 52 in flow communication with a supply 54a and 54b, respectively, of clearcoat material 10 to apply a composite clearcoat over the dried basecoat. The clearcoat materials in the supplies 54a and 54b can be different or the same material. A second flash chamber 56 (similar to flash chamber 40) can be positioned between the first and second clearcoat stations 48 and 50 so that the 15 clearcoat material applied at the first clearcoat station 48 can be flashed under similar conditions described above before application of clearcoat material at the second clearcoat station 50.

The clearcoat can be applied by conventional 20 electrostatic spray equipment such as high speed (e.g., about 30,000-60,000 rpm) rotary bell applicators 52 at a high voltage (about 60,000 to 90,000 volts) to a total thickness of about 40-65 microns in one or more passes. The clearcoat material can be liquid, powder slurry (powder suspended in a 25 liquid) or powder (solid), as desired. Preferably, the clearcoat material is a crosslinkable coating comprising one or more thermosettable film-forming materials and one or more crosslinking materials such as are discussed above. Useful film-forming materials include epoxy-functional film-forming 30 materials, acrylics, polyesters and/or polyurethanes, as well as thermoplastic film-forming materials such as polyolefins can be used. The clearcoat material can include additives such as are discussed above for the basecoat, but preferably not effect pigments. If the clearcoat material is a liquid or 35 powder slurry, volatile material(s) can be included. The

clearcoat material may be a "tinted" material, e.g., comprising about 3 to about 5 weight percent of coloring pigment on a basis of the total weight of the clearcoat material.

5 Preferably, the clearcoat material is a crosslinkable coating comprising at least one thermosettable film-forming material and at least one crosslinking material, although thermoplastic film-forming materials such as polyolefins can be used. A non-limiting example of a waterborne clearcoat is
10 disclosed in U.S. Patent No. 5,098,947 (incorporated by reference herein) and is based on water-soluble acrylic resins. Useful solvent borne clearcoats are disclosed in U.S. Patent Nos. 5,196,485 and 5,814,410 (incorporated by reference herein) and include epoxy-functional materials and polyacid
15 curing agents. Suitable powder clearcoats are described in U.S. Patent No. 5,663,240 (incorporated by reference herein) and include epoxy functional acrylic copolymers and polycarboxylic acid crosslinking agents, such as dodecanedioic acid. The amount of the clearcoat material applied to the
20 substrate can vary based upon such factors as the type of substrate and intended use of the substrate, i.e., the environment in which the substrate is to be placed and the nature of the contacting materials.

In a preferred embodiment, the method of the present
25 invention further comprises curing the applied liquid clearcoat material at a drying station 58 after application over the dried basecoat. As used herein, "cure" means that any crosslinkable components of the material are substantially crosslinked. This curing step can be carried out by any
30 conventional drying technique, such as hot air convection drying using a hot air convection oven (such as an automotive radiant wall/convection oven which is commercially available from Durr, Haden or Thermal Engineering Corporation) or, if desired, infrared heating, such that any crosslinkable
35 components of the liquid clearcoat material are crosslinked to

such a degree that the automobile industry accepts the coating method as sufficiently complete to transport the coated automobile body without damage to the clearcoat. Generally, the liquid clearcoat material is heated to a temperature of about 120°C to about 150°C (184-238°F) for a period of about 20 to about 40 minutes to cure the liquid clearcoat.

Alternatively, if the basecoat was not cured prior to applying the liquid clearcoat material, both the basecoat and the liquid clearcoat material can be cured together by applying hot air convection and/or infrared heating using conventional apparatus to individually cure both the basecoat and the liquid clearcoat material. To cure the basecoat and the liquid clearcoat material, the substrate 12 is generally heated to a temperature of about 120°C to about 150°C (184-238°F) for a period of about 20 to about 40 minutes.

The thickness of the dried and crosslinked composite clearcoat is generally about 12 to about 125 microns, and preferably about 20 to about 75 microns.

An alternative embodiment of a coating system 70 incorporating further aspects of the present invention is shown in Fig. 2. In this system 70, the composite basecoat is applied to the substrate 12 at a single basecoat station 72. Prior to application of the composite basecoat, the substrate 12 can be pretreated, electrocoated and/or primed as described above. The basecoat station 72 can include one or more bell applicators, for example, one bell applicator 74 can be connected to a supply 76 of first basecoat material, e.g., a waterborne coating material substantially free of effect pigment, and another bell applicator 78 can be connected to a supply 80 of second basecoat material, e.g., a waterborne coating material comprising effect pigment. In this system 70, the bell applicator 74 applies the first basecoat material over the substrate 12 in one or more spray passes to produce a substantially non-effect pigment containing first basecoat layer over the substrate. The first basecoat layer can be

- flashed, dried or partially dried by the application of heated air over the substrate 12 at the basecoat station 72. The second basecoat material is applied over the first basecoat layer in one or more spray passes by the bell applicator 78 to
- 5 provide a polychromatic, composite basecoat as described above. The composite basecoat then can be dried in a drying station 44 and clearcoated in a clearcoat zone 46 before curing in a drying station 58, all substantially as described above.
- 10 In the modified system 70 described above, separate bell applicators were connected to the first and second basecoat material supplies 76 and 80. However, in the practice of the invention, a single bell applicator could also be used to apply primer, first and second basecoat materials and/or
- 15 clearcoat over the substrate 12. Any or each of these coating materials can be mixed dynamically before application over the substrate. For example, a selected conventional waterborne color formulation can comprise at least two coating components, a first component having color pigment but which
- 20 is substantially free of effect pigment and a second, effect-pigmented component. With reference to Fig. 3, these two components, along with a conventional clear blending base, can be contained in the first component supply 76, second component supply 80 and third component supply 88,
- 25 respectively, of the coating device 86.

Referring to Fig. 3, predetermined amounts of the substantially effect pigment-free first component (in supply 76) and the base (in supply 88) can be pumped through the applicator conduit 90 and dynamically mixed in the mixer 96 to

30 form the first coating material. The first coating material can be applied onto the substrate 12 in one or more spray passes by flow through the bell applicator 98 to form the first basecoat layer. After application of the first basecoat layer, the flow of the first component (in supply 76) can be

35 stopped and the flow of the second component (in supply 80)

started to mix the second component and the base material in the mixer 96 to form the effect pigment-containing second basecoat material, which is then sprayed over the first basecoat material in one or more spray passes to form the 5 second basecoat layer.

An alternative embodiment of a coating system 104 incorporating additional features of the invention is shown in Fig. 4. The coating system 104 replaces the basecoat zone 20 and clearcoat zone 46 in Figs. 1 and 2 with a multi-dynamic 10 coating zone 106. As explained below, in the multi-dynamic coating zone 106 the substrate 12 can be coated with a primer or functional primer (if desired), a basecoat of a selected color and/or effect and a clearcoat by using a single applicator, e.g., bell applicator 108, connected to a dynamic 15 coating system, e.g., coating system 110 shown in Fig. 5 and discussed further below.

With reference to Fig. 5, the dynamic coating system 110 comprises a first dynamic mixing system 120 having a plurality of coating supplies 122a-122e each containing waterborne, 20 substantially non-effect pigmented coating components preferably of different primary colors, such as red 122a, yellow 122b, blue 122c, white 122d, and black 122e. A separate coating conduit 126a-126e is connected between each coating supply 122a-122e and a conventional transport device, 25 such as pumps 128a-128e, to transport selected coating components from the individual coating supplies 122a-122e through a first mixer 140 and a first conduit 124 to an applicator, such as a bell applicator 108. As described more fully below, the first mixer 140 can be used to mix one or 30 more of the coating components from selected coating supplies 122a-122e and/or a first waterborne base component from a first base supply 130 to form a coating material of a selected color. The pumps 128a-128e can be fixed, positive displacement or variable displacement pumps, such as 0.6 to 35 3.0 cc/revolution positive displacement flushable-face gear

pumps commercially available from Behr Systems Inc. of Auburn Hills, Michigan.

The first base supply 130 is in flow communication with the first conduit 124 through a first base pump 132.

- 5 Additional coating component supplies, such as a weathering component supply 134 or flexibility component supply 136 can also be in flow communication with the first conduit 124 via pumps 138 and 139, respectively. Examples of suitable flexibility and weathering components include ultraviolet absorbers, hindered amine light stabilizers or antioxidants.
- 10 Additionally, one or more primer component supplies 160 containing primer component(s) for application onto the substrate prior to basecoating can be in flow communication with the first conduit 24 by a primer pump 162. Examples of 15 suitable primer components are discussed above.

In a preferred embodiment, the dynamic coating system 110 further comprises a second dynamic mixing system 144 which can be in flow communication with the first dynamic mixing system 120. The second dynamic mixing system 144 can include a plurality of different effect pigment component supplies 146a-146f. For example, supply 146a can contain red mica flakes, supply 146b can contain blue mica flakes, supply 146c can contain green mica flakes, supply 146d can contain yellow mica flakes, supply 146e can contain coarse aluminum flakes, and supply 146f can contain fine aluminum flakes, in flow communication with a second conduit 148 through respective effect pigment pumps 150a-150f. For example, yellow and blue mica flakes can be mixed to form a green tinted material.

The system 144 can further comprise a second base supply 152 containing a second waterborne base component preferably having a different, preferably lower, viscosity than the first base component. The second base supply 152 is in flow communication with the second conduit 148 via a second base pump 154. An optional second mixer 156 is in flow communication with the second conduit 148 upstream of the

position at which the second conduit 148 communicates with the first conduit 124 and can be used to mix one or more of the effect pigment containing components from the supplies 146a-146f with the second base component before entering the first 5 conduit 124. As shown in Fig. 5, one or more of the first supplies 122, e.g., supply 122e, also can be in flow communication with the second conduit 148 by an auxiliary pump 128g to pump one or more selected waterborne coating components directly into the second conduit 148, if desired.

10 With the dynamic coating system 110, the first basecoat material can be mixed dynamically from one or more of the primary-colored coating components received from the first supplies 122a-122e to produce a first basecoat material of a desired color. For example, selected individual primary-15 colored coating components can be pumped from selected first supplies 122a-122e into the first conduit 124 and dynamically mixed in the first mixer 140 to provide the first basecoat material of a desired color before entering the bell applicator 108 and being sprayed onto the substrate 12 in one 20 or more spray passes to form the first basecoat layer. The amount of each coating component and/or first base component, and hence the final color of the first basecoat material, can be controlled using a conventional electronic or computerized control device (not shown) or proportioning valve system such 25 as an RCS (ratio control system) device commercially available from ITW Ransburg or ITW Finishing Systems of Indianapolis, Indiana; or conventional specialized multiple valve control systems commercially available from Behr Systems Inc. of Auburn Hills, Michigan.

30 After application of the first basecoat layer is complete or nearly complete, selected effect pumps 150a-150f and the second base pump 154 are started to blend one or more selected effect pigment containing components from selected effect pigment supplies 146a-146f with the second base component from 35 the second base supply 152. This effect pigment-containing

composition can be mixed with selected coating components from the first supplies 122a-122e in the second mixer 156 and enters the first conduit 124 upstream of the first mixer 140 to produce an effect pigment-containing second basecoat material which is sprayed over the first basecoat material in one or more spray passes to form the second basecoat layer. The effect pigment-containing second basecoat material pushes any remaining first basecoat material out of the first conduit 124 through the bell applicator 108, thus lessening or ameliorating the need for a purging of the bell applicator 108 before application of the second basecoat material. Although in the preferred embodiment described above the mixed second basecoat material passes through the first mixer 140 before entering the bell applicator 108, it should be understood that the second conduit 148 alternatively could be connected directly to the bell applicator 108 such that the mixed second basecoat material would not pass through the first mixer 140 before entering the bell applicator 108. Alternatively, the second mixer 156 can be deleted and all of the components mixed by the first mixer 140.

In the method described above, both the first and second basecoat materials were colored materials, i.e., formed with an amount of a color pigmented coating component from the coating supplies 122a-122e. However, it should be understood that the second mixing system 144 can be used to apply a transparent or semi-transparent second basecoat layer onto the substrate 12 by pumping clear or tinted basecoat component from the second base supply 152 and selected effect pigment-containing components into the first conduit 124 after application of the first basecoat layer(s).

Fig. 6 is a side elevational view of the multi-dynamic coating zone 106 showing the bell applicator 108 mounted on a movable robot arm 116 to permit the bell applicator 108 to move in x, y and/or z directions to coat all or substantially all of the substrate 12 surface. As will be understood of one

of ordinary skill of the automotive coating art, this dynamic coating system 110 can be used to apply a plurality of coating materials, such as functional primers, flexibility coats, weathering coats, clear coats, etc. in series, as desired, 5 onto the substrate 12. Thus, the system 110 could operate to apply substantially all sprayable coatings onto an automotive substrate 12 after an electrodeposition coat or corrosion coat, such as coil-coated BONAZINC, is applied.

For example, with reference to Figs. 5 and 6, a 10 substrate, such as an electrodeposition coated substrate 12, can be moved into the multi-dynamic coating zone 106 where a functional coating, such as functional primer, can be supplied using the system 110 shown in Fig. 5. The primer component from the primer supply 160 can be pumped by the primer pump 15 162 into the first conduit 124 and applied by the bell applicator 108 over the substrate. The primer pump 162 can be stopped and selected coating pumps 128a-128e and the first base pump 132 started to apply the first basecoat material of a selected color over the substrate. The first basecoat 20 material pushes the remaining primer coating material ahead of it as it is mixed in the first mixer 140 and out of the bell applicator 108. The bell applicator 108 can be traversed around the substrate 12 by the robot arm 116 to apply the first basecoat layer onto the substrate 12. The second 25 basecoat material can then be provided by starting the second base pump 154 and selected effect pumps 150a-150f and optionally stopping or slowing the coating pumps 128a-128e and/or first base pump 132. The second basecoat material pushes the remaining first basecoat material ahead of it and 30 out of the bell applicator 108.

To apply a clearcoat over the basecoat, the effect pumps 150a-150f can be stopped and one or both of the first and second base pumps 132 and 154 started. The second base component is preferably of a different, e.g., lower, viscosity 35 than the first base component and can be used as a clearcoat

base. The viscosity of the clearcoat, or any of the other coating material supplied by the dynamic coating system 110, can be varied by the addition of different amounts of the two base components to the dynamically blended coating material.

- 5 It is to be understood that between the applications of the different coating materials in the coating zone 106, the substrate can be flashed, dried or partially dried or cured in the coating zone 106, for example, by the application of heated air.
- 10 After the application of the desired coatings, e.g. primer, basecoat(s) and/or clearcoat(s) in the multidynamic coating zone 106, the substrate 12 may optionally be transported through a flash chamber 112 (similar to flash chamber 40 as described above) and/or through a drying station 15 114 (similar to drying station 44 described above) for final curing.

EXAMPLE 1

In this example, a dynamically mixed coating material is 20 formed according to the present invention.

A steel test panel was coated with commercially available waterborne liquid basecoat and liquid clearcoat materials as described below and was used as a color, appearance, and process "control". The basecoat was applied using a conventional bell/reciprocator gun basecoat process. A clearcoat was applied over the basecoat using a conventional bell application process.

More specifically, the test substrate was an ACT cold rolled steel panel size 10.2 cm by 30.5 cm (4 inch by 12 inch) 30 electrocoated with a cationically electrodepositable primer commercially available from PPG Industries, Inc. of Pittsburgh, Pennsylvania as ED-5000. A waterborne, effect-pigment containing basecoat material (DHWB74101 commercially available from PPG Industries, Inc.) was spray applied in two 35 coating steps. The first basecoat layer was applied by

automated bell spray with 60 seconds spraybooth ambient flash and the second basecoat layer was applied by automated gun spray. The composite basecoat film thickness was about 20 microns with a distribution of approximately 60% bell and 40% gun by volume. Spraybooth conditions of $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($72^{\circ}\text{F} \pm 2^{\circ}\text{F}$) and $65\% \pm 5\%$ relative humidity were used. Following basecoat application, the basecoated panel was dehydrated using an infrared radiation oven commercially available from BGK-ITW Automotive Group of Minneapolis, Minnesota. The panel was heated to a peak metal temperature of $41^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($110^{\circ}\text{F} \pm 2^{\circ}\text{F}$) within three minutes exposure time to infrared radiation. The panel was allowed to cool to ambient condition then clearcoated with liquid DIAMONDCOAT® DCT-5002 coating material (commercially available from PPG Industries, Inc.) and cured for 30 minutes at 141°C (285°F) using hot air convection. The overall film thickness, i.e. basecoat and clearcoat, of this "control" panel was approximately 110 to 130 microns.

A first panel coated according to the present invention (Example A) was prepared in a similar manner to the control panel, but with the following exceptions: the commercially available basecoat composition DHWB 74101 was manufactured as three separate coating components. The first component was similar to conventional DHWB 74101 but had all metallic effect pigment (mica flakes and aluminum flakes) removed. The second component was unmodified DHWB 74101 as is commercially available, i.e., containing mica flake and aluminum flake effect pigments. The third component was a non-pigmented clear base component commercially available from PPG Industries, Inc. as HWB 5000. The components were dynamically mixed as described below using a spray device similar to the coating device 86 shown in Fig. 3 and were applied by bell applicator onto the steel test panels.

The first basecoat material was formed by dynamically mixing the first component (DHWB 74101 substantially free of

effect pigment) with the third component (HWB 5000) using a commercially available Static-Mixing Tube, available from ITW Automotive Group of Indianapolis, Indiana. The ratio of the first to the third component was about 65%/35% volume percent and was controlled by commercially available manual flow-control valves of needle and seat design. This dynamically blended first basecoat material was applied using a Behr bell atomizer (Behr Eco-Bell and 55mm Eco-M Style Cup commercially available from Behr Systems Inc., of Auburn Hills, Michigan) to approximately 12 microns thickness on the panel. This first basecoat layer was flashed for 60 seconds at ambient booth conditions.

A layer of second basecoat material consisting of the second component (DHWB 74101) was applied over the first basecoat material at a thickness of approximately 8 microns using the Behr bell atomizer. The basecoated panel was dehydrated, cooled, clearcoated, and baked to full cure in similar manner to the control panel.

A second panel (Example B) was coated using the same dynamic mixing system and coating components as described above for Example A but the second basecoat layer was applied using a conventional reciprocating gun applicator rather than a bell applicator.

A third panel (Example C) (comparative) was prepared (which was not dynamically mixed) by applying only the control DHWB 74101 effect-pigmented basecoat over the substrate in two layers in a bell/bell application process.

A fourth panel (Example D) was prepared in similar manner to Example A but using a 50%/50% volume ratio of the first and third components which were dynamically blended to form the first basecoat material.

The color and appearance of the coated panels were measured using the following conventional automotive industry tests: Autospect appearance (Gloss + DOI + Orange Peel (OP) = Overall Rating(CO)), and X-Rite Instrumental Color. The

Orange Peel rating, Specular Gloss and Distinction of Image ("DOI") were determined by scanning a 9375 square mm sample of panel surface using an Autospect QMS BP surface quality analyzer device that is commercially available from Perceptron
5 of Ann Arbor, Michigan. The overall appearance rating was determined by adding 40% of the Orange Peel rating, 20% of the Gloss rating and 40% of the DOI rating. The X-Rite color measure was determined by scanning multiple 2580 square mm areas of the panel using an MA68 five angle color instrument
10 commercially available from X-Rite Instruments, Inc.

Table I provides the measured films, flow rates and Autospect Values for the above panels. As will be understood by one of ordinary skill in the automotive coating art, in Table I the "L" values relate to the lightness or darkness of
15 the tested panels using the control panel as a base reference (i.e., 0 value). Positive numbers indicate that the tested panel was lighter than the control and negative values indicate that the tested panel was darker than the control. The "a" values relate to color based on a red/green scale and
20 the "b" values relate to color based on a yellow/blue scale. The listed film thickness are in mils (microns) and the listed flow rates are in cc/min.

Table I

| Test Runs | Gloss | DOI | OP | CO | | | | |
|-----------|----------------------|----------------|----------------------|----------------|----------------------|--------|----------------------|-------|
| Control | 46.5 | 58.5 | 65.5 | 58.9 | | | | |
| Example A | 52.7 | 62.6 | 62 | 60.4 | | | | |
| Example B | 46.3 | 57.3 | 49.9 | 52.1 | | | | |
| Example C | 43.4 | 55.7 | 62.3 | 55.8 | | | | |
| Example D | 54 | 65.8 | 67.8 | 65 | | | | |
| | Films | | | | Flow Rates | | | |
| | 1 st Bell | Recip. | 2 nd Bell | Total | 1 st Bell | Recip. | 2 nd Bell | Total |
| Control | 0.5 (12.7) | 0.25 (6.35) | | 0.75 (19.1) | 140 | 220 | | 360 |
| Example A | 0.45 (11.43) | | 0.35 (8.89) | 0.8 (20.3) | 100 | | 140 | 240 |
| Example B | 0.51 (12.95) | 0.25 (6.35) | | 0.76 (19.3) | 140 | 220 | | 360 |
| Example C | 0.52 (13.2) | | 0.29 (7.4) | 0.81 (20.6) | 130 | | 140 | 270 |
| Example D | 0.51 (12.95) | | 0.31 (7.9) | 0.82 (20.1) | 150 | | 150 | 300 |

As shown in Table I, the substrates coated with dynamically blended coatings (Examples A, B and D) according to the present invention demonstrated generally better Autospect appearance values compared to the conventionally coated control panel. Further, comparison of overall film builds and flow rates demonstrate that the dynamic mixing process of the invention utilizing a bell/bell application process can improve relative transfer efficiency as generally lesser flow rate was required to achieve similar film builds.

Table II provides the X-Rite values for the coated panels discussed above at differing angles of observation.

Table II

| | Angle | L | a | b | ΔL | Δa | Δb |
|-----------|-------|---------|--------|---------|---------|---------|---------|
| Control | 25° | 34.7897 | 43.302 | 16.8694 | | | |
| | 45° | 22.2395 | 35.552 | 18.2556 | | | |
| | 75° | 16.7968 | 31.307 | 18.6413 | | | |
| Example B | 25° | 32.6606 | 41.983 | 16.8072 | -2.1291 | -1.3193 | -0.0622 |
| | 45° | 20.6871 | 33.566 | 17.7494 | -1.5524 | -1.986 | -0.5062 |
| | 75° | 15.9603 | 30.042 | 17.926 | -0.8365 | -1.2655 | -0.7153 |
| Example A | 25° | 33.9612 | 43.174 | 17.1287 | -0.8285 | -0.1282 | 0.2593 |
| | 45° | 22.0118 | 35.633 | 18.1016 | -0.2277 | 0.0801 | -0.154 |
| | 75° | 16.9036 | 31.469 | 18.6956 | 0.1068 | 0.1621 | 0.0543 |
| Example C | 25° | 29.8612 | 42.975 | 16.9268 | -4.9285 | -0.3272 | 0.0574 |
| | 45° | 21.8167 | 34.897 | 18.2786 | -0.4228 | -0.6559 | 0.023 |
| | 75° | 16.5402 | 30.985 | 18.2657 | -0.2566 | -0.3217 | -0.3756 |
| Example D | 25° | 33.5815 | 44.149 | 17.77 | -1.2082 | 0.8465 | 0.9000 |
| | 45° | 21.7508 | 35.09 | 18.163 | -0.4887 | -0.4626 | -0.092 |
| | 75° | 16.5716 | 30.761 | 18.59 | -0.2252 | -0.5466 | -0.0512 |

As shown in Table II, the dynamically mixed coatings,
5 particularly Example A, demonstrate generally acceptable color
compared to the "control" panel.

EXAMPLE 2

This Example illustrates the advantages of using the
10 flash chamber of the present invention on the overall coating
process.

Steel test panels were coated with commercially available
waterborne liquid basecoat and liquid clearcoat materials as
described below and were used as the control. The basecoat
15 was applied using a conventional bell/reciprocator gun
application process. The clearcoat was applied over the
basecoat using a bell applicator process. The test substrate
was an ACT cold rolled steel panel size 10.2 cm by 30.5 cm (4
inch by 12 inch) electrocoated with a cationically
20 electrodepositable primer commercially available from PPG
Industries, Inc. of Pittsburgh, Pennsylvania as ED-5000.

A waterborne, effect pigment-containing basecoat material
(HWBS-28542 for Controls 1 and 3 and DHWB74101 for Control 2,
each commercially available from PPG Industries, Inc.) was
25 spray applied in two coating steps. The first basecoat layer
was applied by automated bell spray with 60 seconds spraybooth
ambient flash and the second basecoat layer was applied by

automated gun spray. The composite basecoat film thickness was about 20 microns with a distribution of approximately 60% bell and 40% gun by volume. Spraybooth conditions of $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($73^{\circ}\text{F} \pm 2^{\circ}\text{F}$) and 65% \pm 5% relative humidity were used.

5 Following basecoat application, the basecoated panels were dehydrated using an infrared radiation oven commercially available from BGK-ITW Automotive Group of Minneapolis, Minnesota. The panels were heated to a peak metal temperature of $41^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($110^{\circ}\text{F} \pm 2^{\circ}\text{F}$) within three minutes exposure time to 10 infrared radiation. The panels were allowed to cool to ambient conditions then clearcoated with liquid DIAMONDCOAT® DCT-5002 coating material (commercially available from PPG Industries, Inc.) and cured for 30 minutes at 141°C (285°F) using hot air convection. The overall film thickness, i.e., 15 basecoat and clearcoat, of these "control" panels was approximately 110 to 130 microns.

"Experimental" panels 1A, 2A and 3A similar to the controls 1, 2 and 3 were coated using an identical spray process with the following noted exceptions. The spraybooth 20 conditions were adjusted to $29^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($85^{\circ}\text{F} \pm 2^{\circ}\text{F}$) and either 55% \pm 5% ("dry") (panel 1A) or 40% \pm 5% ("very dry") (panels 2A and 3A) relative humidity as indicated in Table III. Additional test panels 1B, 2B and 3B were coated identically 25 to the panels 1A, 2A and 3A above, with one important exception. The 60-second flash between first and second basecoat layer applications was not performed in the spraybooth but rather was performed in a flash chamber (box) of the present invention in which the following conditions: 30 $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($72^{\circ}\text{F} \pm 2^{\circ}\text{F}$) and 65% \pm 5% relative humidity with a downdraft velocity corresponding to an air velocity at the surface of the coating of less than about 0.4 m/sec were established.

All panels (control and experimental) for each respective basecoat, were measured for color and appearance using the

following tests which were discussed above: Autospect appearance, X-Rite instrumental color, and profilometer. The profilometer value was determined by scanning a 2 mm by 2 cm path with a contact probe that is automatically dragged across the cured basecoat surface of the panel and a direct reading of surface smoothness value in micro-inches is provided. The profilometer is commercially available from Taylor-Hobson instruments.

Table III provides the respective measured color and appearance values (Delta L, Delta a and Delta b) for each panel. The profilometer readings are in micro-inches (microns).

MESSAGE ENDED

TABLE III

| Panel | Autospec | | | Profil | | | X-Rite Color | | | | | | |
|-----------|----------|------|------|---------|------|-------|--------------|-------|-------|-------|-------|-------|-------|
| | Gloss | DOI | OP | Overall | 25 | 45 | 75 | 25 | 45 | 75 | 25 | 45 | 75 |
| HWBS28542 | | | | | | | | | | | | | |
| Control 1 | 48.3 | 60.5 | 51 | 53.9 | | | | | | | | | |
| 1A | 41 | 54.4 | 45.2 | 47.8 | 0.17 | 0.41 | 0.37 | -0.03 | -0.03 | -0.05 | -0.38 | -0.34 | -0.29 |
| 1B | 45.6 | 58.8 | 48 | 51.5 | 0.41 | 0.51 | 0.14 | -0.03 | -0.03 | -0.10 | -0.44 | -0.38 | -0.40 |
| DHWB74101 | | | | | | | | | | | | | |
| Control 2 | 46.1 | 58.8 | 61.1 | 58.1 | 19 | | | | | | | | |
| 2A | 39.3 | 56.1 | 64.7 | 57.9 | 18 | 1.43 | 1.08 | 0.42 | -0.58 | 0.79 | 0.51 | -1.05 | -0.34 |
| 2B | 46.5 | 60.2 | 63.3 | 59.7 | 21 | 0.74 | 0.48 | 0.16 | -0.07 | 0.28 | 0.13 | -0.12 | 0.00 |
| HWBS28542 | | | | | | | | | | | | | |
| Control 3 | 38.3 | 56.2 | 61.1 | 56 | 22 | | | | | | | | |
| 3A | 22.2 | 41 | 35.4 | 35.4 | 31 | -0.70 | 0.37 | 0.16 | 0.31 | 0.21 | 0.18 | 1.09 | 0.86 |
| 3B | 34.1 | 55.1 | 59 | 53.9 | 20 | 0.78 | 0.38 | 0.17 | -0.15 | -0.10 | -0.13 | -0.62 | -0.47 |

As shown in Table III, the panels 1A, 2A and 3A, i.e., those flashed within the spraybooth, exhibited generally lower Autospect values, color change and/or X-Rite values than the panels 1B, 2B and 3B formed using the flash chamber of the invention. The panels 1B, 2B and 3B, (those sprayed identical to the "dry or very dry" control but flashed in the flash chamber of the invention), exhibited values which compare favorably with Controls 1, 2 and 3.

The coating and drying process utilizing the flash chamber of the present invention appears to promote improved physical appearance and color even for waterborne basecoat coatings applied under atypical spraybooth conditions, i.e., a temperature of $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($72^{\circ}\text{F} \pm 2^{\circ}\text{F}$). It is believed that use of the flash chamber of the present invention would also be useful for replacing existing solventborne coating application processes, which traditionally do not have the application latitude necessary for waterborne coating application, with waterborne coatings without the installation of additional spraybooth climate controls. In the process of the invention, installing a lower cost flash chamber between the first and second basecoat applications, or between subsequent clearcoats, can help promote acceptable droplet coalescence to provide a more desirable coating film. The control climate of the flash chamber can be adjusted easily based on the need to increase or decrease the "wetness" or "dryness" of the droplet deposited film to improve overall coatings film properties both in the wet or as cured.

EXAMPLE 3

This Example illustrates the usefulness of the dynamic mixing process of the present invention not only for blending effect-pigmented and substantially non-effect-pigmented components, but also for dynamically blending different colored components to form a coating of a desired color or shade.

Nine steel test panels were coated with commercially available waterborne liquid basecoat and liquid clearcoat materials as described below (controls 1-9). The test substrates were ACT cold rolled steel panels size 25cm by 25cm (10 inch by 10 inch) electrocoated with a cationically electrodeposable primer commercially available from PPG Industries, Inc. as ED-5000. The commercial waterborne basecoat was a laboratory blend of two materials (HWB9517 Black & HWB 90394 White) both commercially available from PPG Industries, Inc.) In the laboratory, the basecoats were blended manually in the volumetric ratios shown in Table IV to produce nine different gray basecoat colors.

Table IV

| White | White/Gray | | Gray | Gray/Black | | Black |
|-------|------------|--------|--------|------------|--------|-----------------|
| 100% | 95/5% | 85/15% | 75/25% | 50/50% | 25/75% | 15/85% 5/95% |

15

The materials were applied using a Behr Eco-Bell applicator with a 65mm Eco-M smooth edged cup, all commercially available from Behr Systems Inc., of Auburn Hill, Michigan. The color blends were applied by automated bell spray in one coat to a coating film thickness of about 13 microns. Following basecoat application, the basecoated panels were dehydrated in a convection oven such that peak metal temperature of $41^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($110^{\circ}\text{F} \pm 2^{\circ}\text{F}$) within five minutes within the oven was achieved. The panels were allowed to cool 20 to ambient condition then clearcoated with liquid DIAMONDOAT® DCT-5002 coating (commercially available from PPG Industries, Inc.) and cured for 30 minutes at 141°C (285°F) using hot air convection. The overall film thickness of these "control" panels was approximately 90 to 100 microns.

25 Nineteen "experimental" test panels (panels E1-E9 and MD1-MD10) were produced, with panels E1-E9 coated using an identical coating application process as described immediately

above for control panels 1-9 with the following noted exceptions. A dynamic coating device as described above was used to dynamically blend the black and white coating components to form varying gray shades.

5 In the spraying of these nine test panels E1-E9, the mixing process was performed dynamically at the atomizer by control programming of the individual metering pumps to provide the blend ratios listed in Table IV. All other spray and drying process parameters were the same as for the control 10 panels 1-9.

The color of each panel was measured using an X-Rite MA68 five angle color instrument commercially available from X-Rite Instruments, Inc. Color measures were determined by scanning multiple 2580 square mm areas of the panels and using 15 lightness/darkness measure (L value) for the 25°, 45°, and 75° angle. Table V shows that the dynamically-mixed coatings for panels E1-E9 compare favorably to the manually blended coatings of controls 1-9. Some color differences were present for extreme dynamic blends (95% to 5% blends), which are most 20 color sensitive.

TABLE V

| Trial | Blend% white/black | Angle | L value | Blend% white/black | Angle | L value |
|-------------------|--------------------|-------|---------|--------------------|---------------|---------|
| Control 1 | 100% White | 25° | 88.27 | Control 6 | 25% W/75% Blk | 25° |
| | | 45° | 88.14 | | 45° | 25.291 |
| | | 75° | 88.58 | | 75° | 24.727 |
| Panel (E1) | 100% White | 25° | 88.48 | Panel (E6) | 25% W/75% Blk | 25° |
| | | 45° | 88.41 | | 45° | 26.365 |
| | | 75° | 88.87 | | 75° | 26.022 |
| Control 2 | 95%W/5% Blk | 25° | 71.78 | Control 7 | 15% W/85% Blk | 25° |
| | | 45° | 71.51 | | 45° | 25.44 |
| | | 75° | 72.36 | | 75° | 26.951 |
| Panel (E2) | 95%W/5% Blk | 25° | 73.12 | Panel (E7) | 15% W/85% Blk | 25° |
| | | 45° | 73.93 | | 45° | 17.55 |
| | | 75° | 74.72 | | 45° | 16.91 |
| Panel (E2) Repeat | 95%W/5% Blk | 25° | 72.90 | Control 8 | 5% W/95% Blk | 25° |
| | | 45° | 72.65 | | 45° | 18.63 |
| | | 75° | 73.45 | | 45° | 17.669 |
| Control 3 | 85%W/15% Blk | 25° | 59.39 | Panel (E8) | 5% W/95% Blk | 25° |
| | | 45° | 59.03 | | 45° | 16.976 |
| | | 75° | 60.18 | | 75° | 18.434 |

TABLE V (Cont'd)

| | 85% W/15% Blk | 25° | 61.88 | Panel (E8) Repeat | 5% W/95% Blk | 25° | 9.629 |
|-------------------|---------------|-------|-------|-------------------|--------------|-----|--------|
| Control 4 | 45° | 61.54 | | | | 45° | 9.043 |
| | 75° | 62.61 | | | | 75° | 10.349 |
| | 75% W/5% Blk | 25° | 51.46 | Control 9 | 100% Black | 25° | 2.1411 |
| Panel (E4) | 45° | 51.04 | | | | 45° | 1.9522 |
| | 75° | 52.39 | | | | 75° | 1.9712 |
| | 75% W/5% Blk | 25° | 51.74 | Panel (E9) | 100% Black | 25° | 1.9643 |
| Control 5 | 45° | 51.36 | | | | 45° | 1.7794 |
| | 75° | 52.61 | | | | 75° | 1.7419 |
| | 50% W/50% Blk | 25° | 40.23 | | | | |
| Panel (E5) | 45° | 39.72 | | | | | |
| | 75° | 41.27 | | | | | |
| | 50% W/50% Blk | 25° | 40.48 | | | | |
| Panel (E5) Repeat | 45° | 40.00 | | | | | |
| | 75° | 41.41 | | | | | |
| | 50% W/50% Blk | 25° | 40.97 | | | | |
| | 45° | 40.42 | | | | | |
| | 75° | 41.86 | | | | | |
| | | | | | | | |

To compare conventional manual versus multi-dynamic blending of silver effect-pigmented basecoats, a control (MD control) and ten multi-dynamic silver test panels (MD1-MD10) were prepared. The test substrates were ACT cold rolled steel 5 panels size 25cm by 25cm (10 inch by 10 inch) electrocoated with a cationically electrodeposable primer commercially available from PPG Industries, Inc. as ED-5000. As a control (MD control), silver metallic waterborne basecoat (HWB36427 commercially available from PPG Industries, Inc.) was applied 10 using a Behr Eco-Bell applicator with a 65mm Eco-M smooth edged cup to a total coating film thickness of about 20-22 microns. Following the first basecoat application, a 90-second (in-booth) ambient flash was used followed by the second basecoat layer application. The basecoated panel was 15 dehydrated in a convection oven such that peak metal temperature of $41^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($110^{\circ}\text{F} \pm 2^{\circ}\text{F}$) was achieved within five minutes in the oven. The panel was allowed to cool to ambient condition, then clearcoated with liquid DIAMONDOAT® DCT-5002 coating (commercially available from PPG Industries, Inc.) and 20 cured for 30 minutes at 141°C (285°F) using hot air convection. The overall film thickness of this MD control panel was approximately 100 to 110 microns.

In a similar manner, ten dynamically-blended silver coated test panels (MD1-10) were coated following the same 25 process as the MD control silver panel with the following noted exceptions. Each dynamic blend silver test panel was a composite basecoat in which the first basecoat layer was a dynamically blended color as described in Table IV above. The second basecoat layer was applied after a 90-second flash as 30 above, and a layer of HWB 36427 (not dynamically blended) was bell applied to one of two film thickness (6 or 10 microns). For each of the ten test panels MD1-10, the first basecoat layer thickness was about 13 microns. For five of the ten 35 panels (MD 1, 3, 5, 7 and 9) the second basecoat layer thickness was about 10 microns, for the other five test panels

(MD 2, 4, 6, 8 and 10) the second basecoat layer thickness was about 6 microns. All test panels were dehydrated, clearcoated, and cured as defined for the MD control.

The silver MD control and dynamically blended silver 5 coatings on the test panels MD1-10 were measured for color using an X-Rite MA68 five angle color instrument as described earlier. The (L, a, and b values) measuring color space attributes are shown in Table VI.

The data in Table VI demonstrate that the dynamically 10 blended silver coatings in which the second basecoat layer was about 10 microns thick applied over any combination of dynamic gray-scale first basecoat layer generally produce an acceptable match to the silver "MD control".

For each of the five dynamically blended silver coatings 15 in which the silver second basecoat layer was about 6 microns over a first basecoat layer gray-scale, it was found that the "face" and "flop" brightness and color could be altered by the gray shade of the first basecoat layer (face and flop being defined as viewing angles perpendicular to and 75° specular of 20 the panel surface, respectively). Thus, dynamically blending the first basecoat layer to provide different shades of gray was found to also impact the polychromatic effect of the composite basecoat, which could provide automakers with an additional method of varying the polychromatic coatings they 25 may wish to produce.

TABLE VI

| | Angle | L | ΔL | Δa | Δb | X-Rite | Comments |
|-----------------------|-------|--------|------------|------------|------------|--------|------------------------------|
| MD Control | 25° | 101.66 | | | | | |
| | 45° | 65.729 | | | | | |
| | 75° | 43.92 | | | | | |
| Dynamic Blend Silvers | | | | | | | |
| MD1 | 25° | 100.72 | -0.94 | -0.055 | -0.3153 | PASS | Acceptable Color vs. Control |
| | 45° | 64.563 | -1.166 | -0.039 | -0.0615 | WARN | |
| | 75° | 43.754 | -0.166 | -0.0493 | -0.23 | PASS | |
| MD2 | 25° | 102.21 | 0.55 | -0.0709 | -0.3536 | PASS | Equal Travel - Brighter Face |
| | 45° | 65.285 | -0.44 | -0.1163 | -0.2874 | PASS | |
| | 75° | 45.506 | 1.586 | -0.2185 | -0.6481 | FAIL | Lighter Flop |
| MD3 | 25° | 99.876 | -1.784 | -0.0373 | -0.2998 | FAIL | Equal Travel - Darker Face |
| | 45° | 64.036 | -1.693 | 0.0584 | -0.0309 | FAIL | |
| | 75° | 42.899 | -1.021 | 0.0368 | -0.0791 | FAIL | Darker Flop |
| MD4 | 25° | 99.369 | -2.291 | 0.0697 | -0.4012 | FAIL | Equal Travel - Darker Face |
| | 45° | 63.586 | -2.143 | -0.0188 | -0.1217 | FAIL | |
| | 75° | 42.777 | -1.143 | 0.0281 | -0.4238 | FAIL | Darker Flop |
| MD5 | 25° | 100.72 | -0.9423 | -0.041 | -0.1664 | PASS | Acceptable Color vs. Control |
| | 45° | 65.487 | -0.2412 | 0.0356 | 0.022 | PASS | |
| | 75° | 43.578 | -0.3414 | 0.0629 | 0.0547 | PASS | |

TABLE VI (Con't)

| MD6 | 25° | 100.03 | -1.63 | 0.0226 | -0.3731 | FAIL | Equal Travel - Darker Face | | | | |
|------|-----|--------|---------|--------|---------|------|-----------------------------|--|--|--|--|
| | 45° | 63.115 | -2.6131 | 0.0608 | -0.0814 | FAIL | Darker Face | | | | |
| | 75° | 41.339 | -2.5808 | 0.1101 | -0.1293 | FAIL | Darker Face | | | | |
| MD7 | 25° | 96.974 | -4.6872 | 0.046 | -0.0723 | FAIL | Lesser Travel - Dark Face, | | | | |
| | 45° | 64.684 | -1.0449 | 0.066 | -0.0164 | WARN | Dark Face, | | | | |
| | 75° | 44.066 | 0.1468 | 0.0914 | 0.0237 | PASS | Equal Flop | | | | |
| MD8 | 25° | 97.545 | -4.1159 | 0.0088 | -0.1745 | FAIL | Lesser Travel - Dark Face, | | | | |
| | 45° | 63.4 | -2.3287 | 0.0546 | -0.016 | FAIL | Dark Face, | | | | |
| | 75° | 41.808 | -2.1116 | 0.1151 | -0.1329 | FAIL | Dark Face | | | | |
| MD9 | 25° | 100.18 | -1.4813 | 0.0058 | -0.0688 | WARN | Acceptable Color vs. | | | | |
| | 45° | 66.768 | 1.0391 | 0.0466 | 0.0837 | WARN | Control | | | | |
| | 75° | 44.884 | 0.9644 | 0.0739 | 0.0888 | WARN | | | | | |
| MD10 | 25° | 97.715 | -3.9458 | 0.0603 | -0.181 | FAIL | Equal Travel - Darker Face, | | | | |
| | 45° | 62.762 | -2.9665 | 0.1156 | 0.0744 | FAIL | Dark Face, | | | | |
| | 75° | 40.355 | -3.5648 | 0.191 | 0.3178 | FAIL | Dark Face | | | | |

As discussed further below, the dynamic mixing process of the invention also can help provide a total coating package (first and second basecoat layers) having a higher solids content (total pigment and binder without volatiles) than using a conventional waterborne silver coating material alone, thus reducing the amount of organic volatiles and paint usage compared to conventional automotive painting applications.

Table VII shows the theoretical percent of solids present in three conventional waterborne coating materials, e.g., black, white and silver, each commercially available from PPG Industries, Inc. of Pittsburgh, Pennsylvania.

15

TABLE VII

| Coating System Package | Theoretical Solids (%) |
|------------------------------------|------------------------|
| Commercial Coatings | |
| HWB90394 (white) | 53.0 |
| HWB9517 (black) | 38.6 |
| HWB36427 (silver) | 40.6 |
| Volumetric Blends + Silver: | |
| 100% white (HWB90394) | 49.0 |
| 100% black (HWB9517) | 39.3 |
| 75% black/25% white | 42.1 |
| 75% white/25% black | 46.9 |
| 50% black/50% white | 44.5 |

For example, a silver coating using only conventional HWB35427 would be expected to have a total solids content of about 40.6%. However, as shown in Table VII, the total solids content for a silver colored coating can be increased by applying a first basecoat layer of white or a dynamic mixture of white and black and then applying the silver coating over the first basecoat layer. It should be noted that the solids content using the black basecoat material alone was less than that for the silver coating alone.

The process of the present invention can provide improved color flexibility and greater total package solids compared to the use of conventional metallic basecoat materials alone.

5 The dynamic mixing process provides the ability to have a large color palette for both solid color and metallic colors using relatively few blending base colors or metallic blending colors. Solids in the total basecoat package also can be increased. A controllable color contrast change can be achieved based on the blend combination of the first basecoat

10 layer solid color and the blend combination and relative film thickness of the second basecoat layer metallic color.

EXAMPLE 4

In this example, atomized droplet size and droplet size distribution measurements were used to characterize and compare the quality of atomized droplets produced from a typical bell atomizer.

A Malvern Spraytec Particle Size Analyzer as commercially available from Malvern Instruments Inc. was set-up in a downdraft spraybooth to measure the atomized droplet cloud produced from a bell atomizer with a 57 mm automotive type bell cup, both commercially available from ITW Automotive of Highland Park, Michigan. A spraybooth downdraft velocity of approximately 0.4 m/sec with spraybooth conditions of $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ($72^{\circ}\text{F} \pm 2^{\circ}\text{F}$) and 65% \pm 5% relative humidity were used. The liquid coating atomized was a silver metallic waterborne automotive coating commercially available from PPG Industries, Inc. as HWB 9517.

The initial bell operational parameters were 40,000 RPM bell speed, 30 psi shaping air, and 150 cc/min coatings flow rate, which is a typical set of operating parameters for conventional automotive applications. This condition was designated as the "Control". Experiments were conducted in which the parameters of bell speed and coatings flow rate were varied as shown in Table VIII.

TABLE VIII

| Trial No. | Bell Speed (RPM) | Shaping Air (psi) | Fluid Delivery Rate (cc/min) |
|-------------|------------------|-------------------|------------------------------|
| 1 | 20,000 | 30 | 75 |
| 2 | 20,000 | 30 | 100 |
| 3 | 40,000 | 30 | 100 |
| 4 | 55,000 | 30 | 100 |
| 5 | 55,000 | 30 | 150 |
| control (C) | 40,000 | 30 | 150 |
| 6 | 20,000 | 30 | 150 |
| 7 | 20,000 | 30 | 250 |
| 8 | 40,000 | 30 | 250 |
| 9 | 55,000 | 30 | 250 |
| 10 | 55,000 | 30 | 205 |

Atomized droplet cloud measurements were performed using the Malvern Spraytec instrument, which uses a laser light beam of approximately 10 mm in diameter to pass through the atomized droplet cloud. Receptor cells capture the angles of deflection of the light beam from the atomized droplets, which deflection angle is directly related to the droplet size that caused the deflection. The Malvern instrument data was used to produce droplet size and droplet size distribution tables and curves. The droplet data tables and/or curves were compared to determine similarities and differences between spray conditions. Table IX is a summary table of the conditions tested in this example. Data values within the table represent the percent of measured droplets that fall within the respective droplet size ranges.

TABLE IX

| Trial | Droplet Size Ranges (Microns) | | | | | | >60 |
|-------|-------------------------------|-------|-------|-------|-------|-------|-------|
| | 0-5 | 6-9 | 10-14 | 15-30 | 31-40 | 41-60 | |
| 2 | 0.000 | 0.000 | 0.012 | 0.076 | 0.388 | 0.430 | 0.093 |
| 3 | 0.000 | 0.008 | 0.032 | 0.209 | 0.504 | 0.222 | 0.025 |
| 4 | 0.000 | 0.034 | 0.080 | 0.384 | 0.393 | 0.099 | 0.009 |
| 5 | 0.000 | 0.031 | 0.067 | 0.313 | 0.418 | 0.149 | 0.021 |
| C | 0.000 | 0.006 | 0.028 | 0.189 | 0.456 | 0.271 | 0.051 |
| 6 | 0.000 | 0.000 | 0.013 | 0.087 | 0.364 | 0.412 | 0.124 |
| 7 | 0.000 | 0.001 | 0.015 | 0.122 | 0.315 | 0.361 | 0.185 |
| 8 | 0.000 | 0.007 | 0.030 | 0.199 | 0.397 | 0.298 | 0.069 |
| 9 | 0.000 | 0.026 | 0.062 | 0.266 | 0.424 | 0.190 | 0.032 |
| 1 | 0.000 | 0.000 | 0.019 | 0.126 | 0.485 | 0.215 | 0.070 |
| 10 | 0.000 | 0.030 | 0.068 | 0.217 | 0.463 | 0.212 | 0.026 |

Table IX demonstrates that changes in the spray parameters produce changes in the droplet size distributions.

Table X is a grouping of spray parameter conditions from Table VIII in which the bell speed and coating flow rate differ for a set shaping air setting, i.e., 30 psi.

TABLE X

| Trial | Droplet Size Ranges (Microns) | | | | | >60 |
|-------|-------------------------------|-------|-------|-------|-------|-------|
| | 0-5 | 6-9 | 10-14 | 15-30 | 31-40 | |
| 4 | 0.000 | 0.034 | 0.080 | 0.384 | 0.393 | 0.099 |
| 5 | 0.000 | 0.006 | 0.028 | 0.189 | 0.456 | 0.271 |
| 7 | 0.000 | 0.001 | 0.015 | 0.122 | 0.315 | 0.361 |
| | | | | | | 0.185 |

Table X demonstrates that changes in the spray parameter conditions result in changes in the droplet size distributions.

Table XI is another grouping of spray parameter conditions from Table VIII in which the bell speed and atomization air are held constant and the coating flow rate is varied. This grouping is likened to the typical process of how multiple atomizers used within a multiple atomizer zone are controlled.

TABLE XI

| Trial | Droplet Size Ranges (Microns) | | | | |
|-------|-------------------------------|-------|-------|-------|-------|
| | 0-5 | 6-9 | 10-14 | 15-30 | 31-40 |
| 3 | 0.000 | 0.008 | 0.032 | 0.209 | 0.504 |
| 5 | 0.000 | 0.006 | 0.028 | 0.189 | 0.456 |
| 8 | 0.000 | 0.007 | 0.030 | 0.199 | 0.397 |

Table XI demonstrates that changes in coating flow rate when bell speed and shaping air are held constant also produce differences in the droplet size distributions when compared to 5 one another. The differences are lesser in this grouping than for the grouping of Table X, however differences are still noted.

Table XII is a different grouping of spray parameter conditions from Table VIII in which the atomization energy 10 (bell speed x shaping air supply) and coatings flow rate are balanced as described below in comparison to the "control" parameter. The coating flow rate is varied but the atomization energy is adjusted such that the control ratio of 15 atomization energy to coating flow rate is substantially maintained.

TABLE XII

| Trial | 0-5 | 6-9 | 10-14 | 15-30 | 31-40 | 41-60 | AE/CF |
|-------|-------|-------|-------|-------|-------|-------|-------|
| C | 0.000 | 0.006 | 0.028 | 0.189 | 0.456 | 0.271 | 8.0 |
| 1 | 0.000 | 0.000 | 0.019 | 0.126 | 0.485 | 0.215 | 8.0 |
| 10 | 0.000 | 0.030 | 0.068 | 0.217 | 0.463 | 0.212 | 8.0 |

For the "control", the atomization energy to coating flow rate ratio is $(40 \times 30)/150 = 8.0$.

For Trial No. 1, the coating flow rate was reduced to 5 75 cc/min but the bell speed was changed to 20,000 rpm to maintain the control ratio, i.e. the control ratio is $(20 \times 30)/75 = 8.0$.

For Trial No. 10, the bell rotational speed was increased to 55,000 rpm but the coating flow rate was adjusted to 10 205 cc/min to maintain the control ratio, i.e. the control ratio is $(55 \times 30)/205 = 8.04$.

As shown in Table XII, the droplet size ranges in the 31-40 and 41-60 micron ranges compare favorably for each of these systems, i.e. control and Trials 1 and 10. Table XII demonstrates that changes in fluid delivery and bell speed can be balanced in accordance with the control ratio to produce droplet size distributions that are similar to the "control".

As will be understood from the above discussion, the present invention provides methods and devices for applying a 20 basecoat, such as an effect pigment-containing composite basecoat, over a substrate using one or more bell applicators. The present invention also provides a control process for controlling the operation of multiple applicators in a coating system and dynamic mixing systems for versatile color 25 blending.

It will be readily appreciated by those skilled in the art that modifications may be made to the invention without departing from the concepts disclosed in the foregoing description. Accordingly, the particular embodiments 30 described in detail herein are illustrative only and are not limiting to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.